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Montana synthetic natural gas demand study

MONTANA SYNTHETIC NATURAL GAS DEMAND STUDY

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MONTANA

SYNTHETIC NATURAL GAS

DEMAND STUDY

DRAFT

Final Report

prepared for

STATE OF MONTANA AND U.S. FEDERAL ENERGY ADMINISTRATION
(FEA-CA-05-60743-00)

prepared by

Environmental Engineering Division
MONTANA ENERGY AND MHD RESEARCH AND DEVELOPMENT INSTITUTE
Butte, Montana

December 1976

STATEMENT

This report was prepared by professional consultants at the Montana Energy and MHD Research and Development Institute under contract with the Office of the Governor, State of Montana, with funds provided by a state federal cooperation agreement with the U.S. Federal Energy Administration (FEA). Neither the Office of the Governor nor FEA has approved the report, nor do they guarantee the accuracy or the completeness of the data. The statements, findings, conclusions, and recommendations contained in the report are soley those of the contractors and do not necessarily reflect the views of the Governor of Montana or FEA. This report is the result of tax-supported research and, as such, is not copyrightable. It may be reprinted freely with the customary crediting of source.

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I. INTRODUCTION

As in many other regions of the country, the supply of natural gas in Montana may not be sufficient to meet future needs. One method to avoid this problem in Montana is to produce SNG (synthetic natural gas) using the state's extensive coal reserves. The purpose of this study is to determine the demand for SNG in Montana through 2000 A.D.

Determining the demand for SNG essentially is a balancing problem. The SNG demand is the additional production required to balance natural gas requirements with the supplies available. Thus, the demand for and supply of natural gas must be determined before the demand for SNG can be found. Natural gas cannot be considered alone as it competes with other fuels. Major conversion of industry gas uses to coal and electricity certainly are possible and can affect the demand for natural gas significantly. The cost of producing SNG is likely to be different from the natural gas obtained from conventional sources. Thus, SNG may enter the market place and compete at different price levels than other natural gas.

The approach used here was to develop a model of Montana's economy on which energy demands can be based. The complete documentation of the model is contained in appendices A-D of this report. The industrial and commercial demands for energy are based upon the levels of activity in the corresponding sectors of the economy while residential demands are based upon the number of households and their income. In addition, the effects of inter-fuel competition and conservation are considered.

The primary modeling technique used is dynamic systems simulation. This methodology deals with the forces causing change in the economy and should be well suited for the transients which are likely in Montana's future. It also allows the model to be based more closely on the actual processes and actions which occur in Montana's economy. The dynamic simulation is combined with input/output analysis in determining levels of economic activity. The use of the input/output analysis assists in obtaining more detail in this critical area.

Once developed, the model was used to analyze the effects of inter-fuel substitution and various energy conservation scenarios. Some industries in Montana recently switched from gas to other fuels, and more substitutions are projected for the future. Residential heating is a major gas use in Montana; conservation in that area was modeled for several projected gas price levels. Fuel substitution and energy conservation will be significant factors in the gas demand picture for Montana.

II. DYNAMIC SYSTEM SIMULATION MODEL OF MONTANA'S ECONOMY

The demand for natural gas (including SNG) in Montana is determined by the level of activity in the Montana economy. The SNG study group felt that it would be worthwhile to develop a computer model of the economy to aid in demand analysis. A dynamic systems simulation approach[1] was selected as most appropriate for the model. This approach takes into account the various interrelationships and feedback effects in the economy.

The model is composed of several sub-models each dealing with a certain area of the economy. Overall structure for this model is illustrated in Figure 1. The model is similar in concept to the Oregon State Simulation Model,[2] and the structure of some of the sub-models basically is the same as their Oregon counterparts. The Montana Futures Project[3] input/output model also was used in the formulation of the model. Each sub-model is discussed separately in the following sections.

A. Demographic Sub-Model

The demographic sub-model predicts both the number of people that will be in Montana and the number of households in the state. Projections are based upon current population and predicted net migration. Migration is affected by the difference between Montana unemployment levels and national unemployment levels.

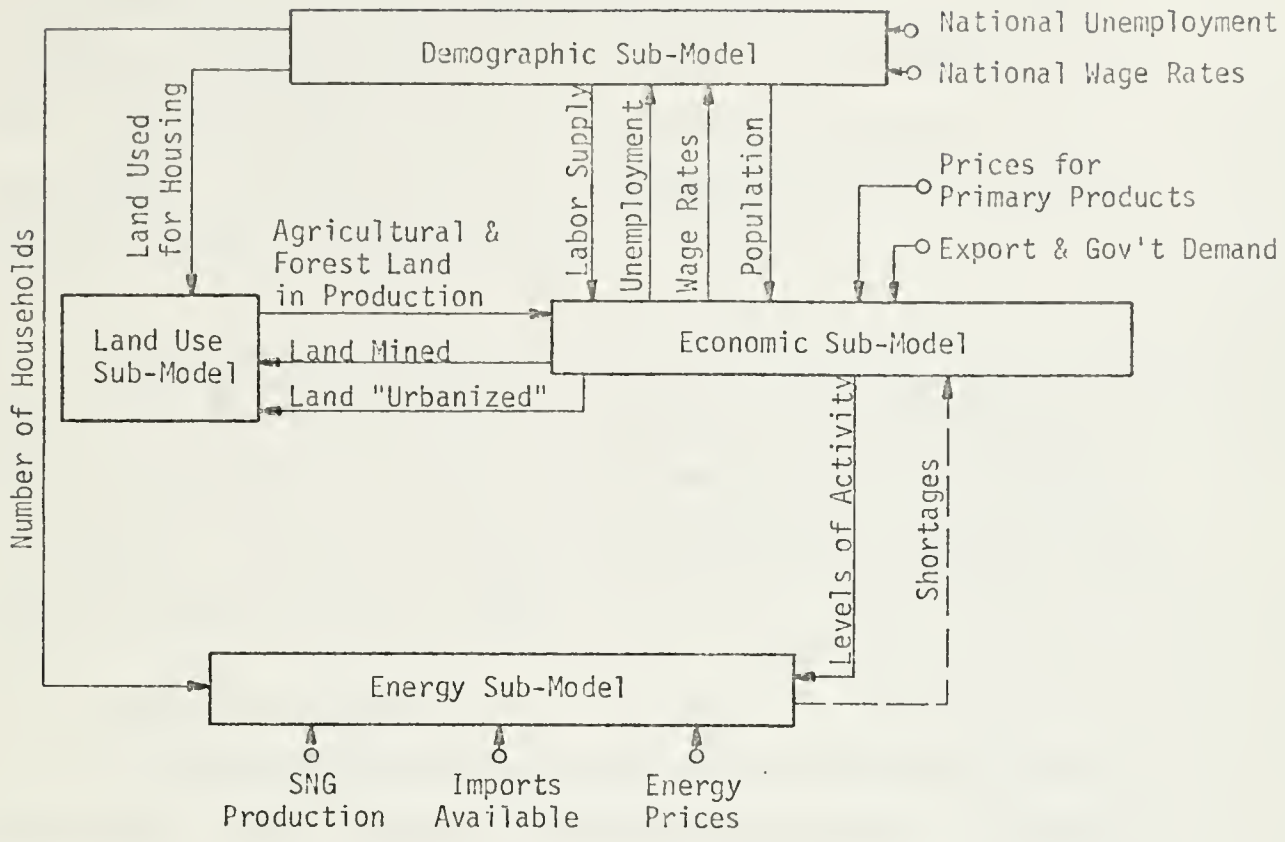

Figure 1.--Overview of Model Structure

B. Land Use Sub-Model

The land-use component maintains a current inventory of land in each of six categories. Residential land demand is a function of the rate of new household formation and the residential conversion density (which originates in the demographic component). Demand for commercial/industrial land is determined by the rate of employment and the employees/acre. This is generated by activity levels in the industrial sectors of the economic component. The figure for total land converted from agricultural to urban land is obtained from the sum of the demand for residential and commercial/industrial land.

Mining land is converted from agricultural land by a scenario variable derived from standard coal production per year. Waste land is derived by taking the product of the land mined and the fraction of revegetation (this fraction being a technical policy input).

Forest land accounts for all the land upon which commercially harvestable timber is growing. Agricultural land can be converted to forest land; however, this is unlikely in Montana. Forest land may be converted to wilderness land and vice versa by policy input.

C. Economic Sub-Model

Five separate models are used for the primary economic activities: agriculture, forestry, coal mining, oil and gas production, and non-energy mining. Since the output of the petroleum refining and primary metal processes depends mainly on the amount of Montana oil produced plus crude oil imports and metal mined, they also are considered separately. This part of the model can be considered supply limited. The output of these sectors plus consumer expenditures, export demands, government spending, and capital expenditures, drive an input/output model for the rest of the economy. These activities can be considered demand limited. The outputs then are used to determine total employment and income.

Each of the models for the primary activities and for petroleum refining and primary metal processing will be discussed separately. The capital investment and employment

models also are discussed separately.

D. Agricultural Sub-Model

The agricultural sub-component of the economic model is divided into two parts, agricultural production and capital formation.

Agricultural Production: The amount of agricultural land and the level of capital employed are combined (utilizing a modified Cobb-Douglas production function)[2] to generate the production level. The gross agricultural production is converted to net farm receipts by subtracting the aggregate expenses incurred in production. The production expenses fall into four categories: direct operating expenses, labor expense, interest expense, and property tax expense.

Capital Formation: The agricultural capital formation model starts with the value of net farm receipts developed in agricultural production and determines the resulting change in capital. If net farm receipts are greater than zero, a portion is used to purchase new capital. Depreciation of capital stock is assumed to occur at a rate that is proportional to the installed level.

In the event that net farm receipts are less than zero, liquidation can occur. If the magnitude of the loss exceeds a specific fraction of gross production, it is assumed that the agricultural community will be forced to further reduce the level of owned capital stock by liquidating it at its

salvage value; otherwise, capital is simply allowed to depreciate without replacement.

E. Logging Sub-Model

The principal assumption in the logging sub-model is that the logging sector of Montana's economy in the long run is driven by the projected inventory of standing mature sawtimber available to be cut in each year. The total capital to harvest the allowed timber cut is adjusted by technology and the future capital required. Additional capital is a relationship between the total capital required and the present level of capital.

The annual cutting rate is determined by calculating the difference between the standing timber available to cut and the maximum possible cut given the current level of installed capital.

F. Coal Mining/Non-Energy Mining Sub-Model

The models for coal mining and non-energy mining are identical in structure. Only the parameters are different. For the sake of simplicity, they will be discussed together here.

The productivity and cost for mining are determined by relating mining cost and capital cost functions to the total quantity that has been mined. A cost distribution function determines what fraction of total possible output is economical. This is used to determine the actual output. Profit rate and the rate of return are calculated by subtracting

mining expenses from mining income.

G. Oil and Gas Sub-Model

The oil and gas model consists of parallel, coupled models--one for oil discovery and production and one for gas discovery and production. The models are coupled since oil production normally has some gas production associated with it and production from gas fields usually results in the production of some liquids as well. Similarly, when exploration for oil fields is carried out, there is some probability of finding a gas field (or vice versa). The following discussion deals only with oil exploration and production since the structure is the same for gas.

When oil is discovered, it is placed in the producing level and information is retained as to the age of each discovery. Four functions are required to describe the performance of producing reservoirs.

The production function traces a typical reservoir through the various stages of discovery, steady-state production, and finally, a long period of steady decline to depletion. The operating expense function shows the expenditures required to operate a producing field of a given age. The investment function gives the rate at which investment must be made in order to develop and maintain a field.

The variable cost of production is similar to the operating expense function except that it describes the cost

on the basis of unit of production for fields of each age. This function is used to compare the price to the variable cost.

The total oil production is the sum of the oil produced in oil fields plus the liquids produced in natural gas fields. The total income for oil production is then the oil produced in oil fields multiplied by the oil price--plus the gas produced in the oil fields multiplied by the wellhead gas price. The expenses for the production come from the total operating expenses plus the costs for capital. The net profit rate per barrel of oil is determined by subtracting the expenses from the income and dividing by the production rate.

The rest of the model deals with exploration. Two additional functions are required here. The depletion function gives the increase in drilling required for additional discoveries as more and more oil is discovered. The investment function gives the rate of investment in terms of the profit rate.

H. Petroleum Refining Sub-Model

Montana's petroleum refining is very closely related to the output of the petroleum sector. It also is dependent upon imports of crude oil. These factors are more important than actual demand for refinery products in Montana. Therefore, it must be considered separately rather than with the economic output model.

The vast majority of the refinery capacity in Montana is located around the Billings area. However, the pipeline system is such that the oil produced in the eastern part of the state is not available to these refineries.

In 1975 81% of the total oil refined in Montana was imported crude oil. However, it is difficult to predict the availability of crude oil imports in the future, especially Canadian imports. Thus, the refinery output will depend upon the available Montana production plus the available imports or the maximum output of current capacity.

I. Primary Metals Sub-Model

The output of the primary metals sector of the economy is dependent primarily upon the output of the metal mining sector. It also is very energy intensive. Primary metals output is assumed to be proportional to the non-energy mining output.

J. Economic Output Model

The economic output model is simply an input/output model for Montana. Outputs for agriculture, forestry, coal mining, oil and gas, non-energy mining, petroleum refining, and primary metals are all determined elsewhere. The direct input/output coefficients are used to determine the demands for other products due to these outputs. These demands then are treated as demands exogenous to the input/output model. Additional exogenous demands arise from consumer spending, exports, and government spending.

K. Capital Investment Sub-Model

The capital investment for the primary sectors is determined in their individual models. The same capital investment structure is used for all non-primary sectors.

The model uses exponential delays to average both the output and the rate of change for a sector. The averaged rate of change is added to the depreciation rate to get the total investment rate required. However, if this rate is negative, there is no investment. If it is positive, it is multiplied by the averaged output and the capital output ratio to determine the actual investment.

L. Employment Sub-Model

Employment is divided into three groups: agricultural, non-agricultural primary, and derivative employment. The primary reason this division is made is because wage rates for the different groups vary considerably. Levels of employment are determined from economic output and employee/output rates. Government employment should relate to government spending in much the same way that private employment relates to output.

The employment for the various sectors are summed to determine the total employment. The total work force available is determined by multiplying the total population by the employee/population projection. The total employment and the total work force are compared to determine the unemployment rate.

M. Energy Sub-Model

The energy sub-model is divided into a fairly detailed demand section and a simple supply section that obtains much of its information from the economic sub-model.

The demand for energy is analyzed along the traditional lines of residential, commercial, and industrial usage. Each part of the demand is treated somewhat differently and is discussed separately.

Residential Demand---The demand for residential energy is divided among its various end uses. These uses include the following factors:

Space Heating
Water Heating
Kitchen Ranges
Refrigeration
Clothes Drying
Air Conditioning
Other

The actual residential demand for a particular form of energy by a particular end use is determined by the following relationship:

$$E_{i,j} = A_{i,j} \times S_{i,j} \times TH$$

where

$E_{i,j}$ is the consumption of energy type i by end use j,

$A_{i,j}$ is the average consumption of energy for this type of end use in a typical household,

$S_{i,j}$ is the saturation of type j end use using energy type i, and

TH is the total number of households.

Industrial Demand---Industrial energy demand is determined separately for each sector. The use of a particular type of energy in a given sector is determined by the following relationship:

$$E_{i,j} = A_{i,j} * O_j$$

where

$E_{i,j}$ is the use of energy type i in sector j,

$A_{i,j}$ is the energy type i consumption per unit of output, and

O_j is the output of sector j.

Commercial Demand---There appears to be very little data available which gives details on commercial energy demand. This is a common problem for all energy studies. Usually everything that is left over is lumped into the commercial category.

The output for the commercial sector also was treated as a residual. It consists of all trade, service, and government sectors; the construction sector; and the communications sector. Total output for these sectors was 1,924 million dollars in 1974. The Montana Business Quarterly reports that income in Montana increased approximately 5% from 1972 to 1974. It was assumed that commercial output increased similarly. An adjusted output of 2,021 million dollars then was calculated. This value for output was used to calculate the energy coefficients.

N. Energy Supply

The energy supply part of the model is relatively simple compared to the energy demand. Most of the actual supply modeling is done in the economic part of the model which gives the total production of gas, oil, and coal. However, most of the coal production is destined for export, and a significant part of the oil and gas production is not available for Montana use.

O. Energy Conservation in the Residential Sector

The amount of natural gas used in the residential sector could change considerably as prices increase. There may be reductions in energy consumption due to fuel shifts, investments in home heating and energy saving devices, or merely by an adjustment in living habits. These changes could affect the total demand for natural gas significantly.

Our study of residential energy conservation focused on home heating since it dominates natural gas consumption in this sector. The substitution of other fuels for natural gas was eliminated since other fuels are not likely to be cost competitive to the point of causing major fuel shifts in home heating even when price increases are considered. However, existing methods for reducing heating requirements through home insulation were found to be cost effective.

Energy savings and cost data can be used to determine the return for installing insulation for various price scenarios in terms of a payback period.

A simple conservation model simulates the installation of insulation and the impact it has on natural gas for heating a typical Montana home.

In addition to the reductions resulting from insulation, significant energy saving could result from modified living habits due to high natural gas prices.

III. SCENARIO PRESENTATION

A. Baseline Gas Demand in Montana

A baseline gas demand in Montana was established for the period between now and the year 2000 (see Figure 2). The baseline demand assumes very little home energy conservation. Industrial fuel substitution is assumed to be minimal also. This baseline represents a continuation of current policies and practices.

The demand for natural gas is not considered to be supply limited. Significant overall economic growth is anticipated in Montana, but not all sectors of the economy will experience the growth. The petroleum industry and metal mining and processing are expected to provide a smaller proportion of economic activity in the year 2000 than now. This decline is due to a shrinking resource base and steadily increasing costs of extraction.

Forestry and kindred industries are expected to grow modestly but steadily through the end of this century. Agriculture will remain the dominant industry throughout the remainder of this century and shows significant economic growth. The coal industry should grow dramatically and will be the second largest industry in Montana by the year 2000.

This mixed economic activity will change the proportion of fuel demand in Montana. One rather dramatic effect of this change in fuel usage is a much smaller increase in natural gas

Figure 2.--Montana Natural Gas Demand

demand than has been experienced in the past. The demand for the baseline case would be 83 billion cubic feet in 1980 and approximately the same in 1985. Demand would be about 89 billion cubic feet in the year 2000, with peak demand in the mid-90's of around 94 billion cubic feet per year.

B. Residential Conservation Effects

The baseline case for gas demand assumes very little residential energy conservation. The first case to be considered after establishment of the baseline is the probable effect of significant home energy conservation. Since the greatest volume use of residential gas is in home heating, the focus was concentrated in this area. Reduced energy use per household is due to increased insulation, improved weather-stripping, and the use of storm windows and doors. Additional savings are realized from altered living habits. Home energy conservation primarily is a function of gas price.

Figure 2 shows the effect of home energy conservation on gas demand in Montana. The gas price is assumed to rise from current levels to $4.50/MCF in the year 2000. Gas demand approximates 80 billion cubic feet in 1980 and declines to 77 billion cubic feet by 1985. Demand for natural gas will be about 74 billion cubic feet in the year 2000, with a peak in the mid-1990's of approximately 85 billion cubic feet per year.

C. Industrial Energy Substitution

No industrial energy substitution is assumed in the baseline gas demand for Montana. The next step in the analysis is to see how substantial substitution of other fuels for gas affects gas demand. Fuel switches were divided into two types. Industrial fuel substitutions considered firm are those that currently are underway or are scheduled for completion by 1980. These switches in fuel usage are caused by various factors such as environmental concern, fuel supply uncertainties, and relative fuel costs. The industrial fuel substitution then was extrapolated beyond 1980. The extrapolated fuel substitution is a function of relative fuel costs and the payback period for conversion.

The effects of both types of industrial fuel substitution are shown in Figure 3. One curve shows the effects of firm substitutions only, while the lower curve represents demand when firm substitutions and extrapolated substitutions are combined. The combined substitutions project a gas demand of 69 billion cubic feet in 1980. Demand falls off to 61 billion cubic feet in 1985 and is about 62 billion cubic feet by the end of this century. Peak usage in the mid-1990's is approximately 67 billion cubic feet. The price of gas is assumed to rise from today's prices to $4.00/MCF by the year 2000.

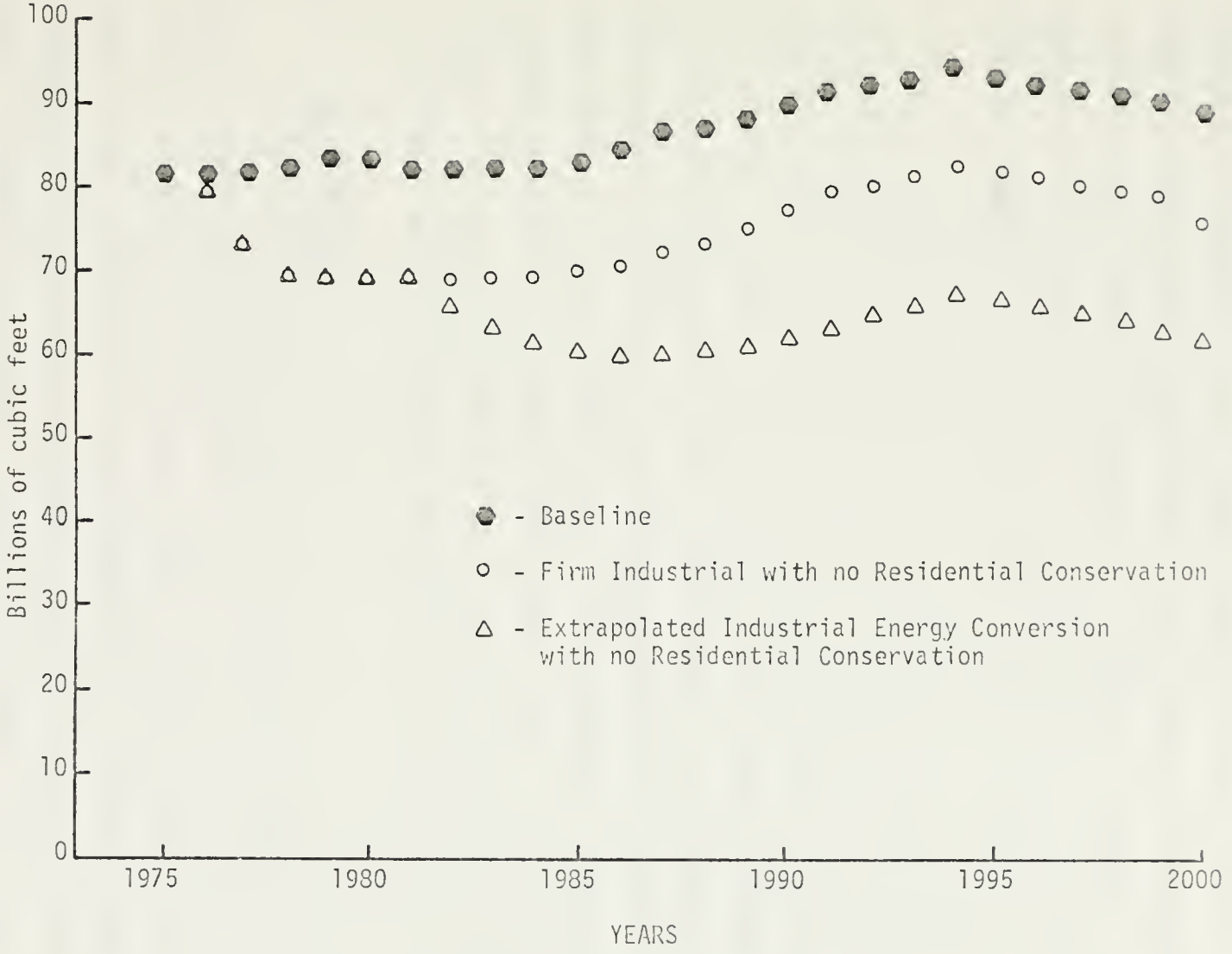

Figure 3.--Montana Natural Gas Demand

D. Gas Price Effects

After showing the general effects residential gas conservation and industrial fuel substitution can have on gas demand, the SNG study group used several gas price scenarios to determine a range of possible gas demand in Montana. Gas demand curves shown so far have assumed a rise in gas prices from the current level to $4.50/MCF in the year 2000.

Three price scenarios were selected as representative of low, medium, and high gas prices. Prices are for residential gas use; industrial gas prices were assumed to be lower by $.50/MCF. Figure 4 illustrates the gas demand expected at the specified price levels. Also shown on the graph are the baseline demand and a curve representing the effects of firm industrial fuel substitution (no residential conservation or extrapolated fuel substitution after 1980). Prices assumed for the low, medium, and high gas prices are shown in Figure 5. Table 1 summarizes the results shown in Figure 4.

E. Conclusions

Natural gas demand in Montana (including demand for SNG) will decline from the present level of about 80 billion cubic feet per year to 50-70 billion cubic feet per year by the year 2000. The decline in gas demand after 1980 is caused primarily by projected increases in the gas price to consumers. Even for modest increases in price (to $3/MCF in the year 2000), the deamnd is reduced by about 30% from current demand. A price of $3/MCF by the year 2000 is an average price growth rate of only about 2.5% per year. An average price growth

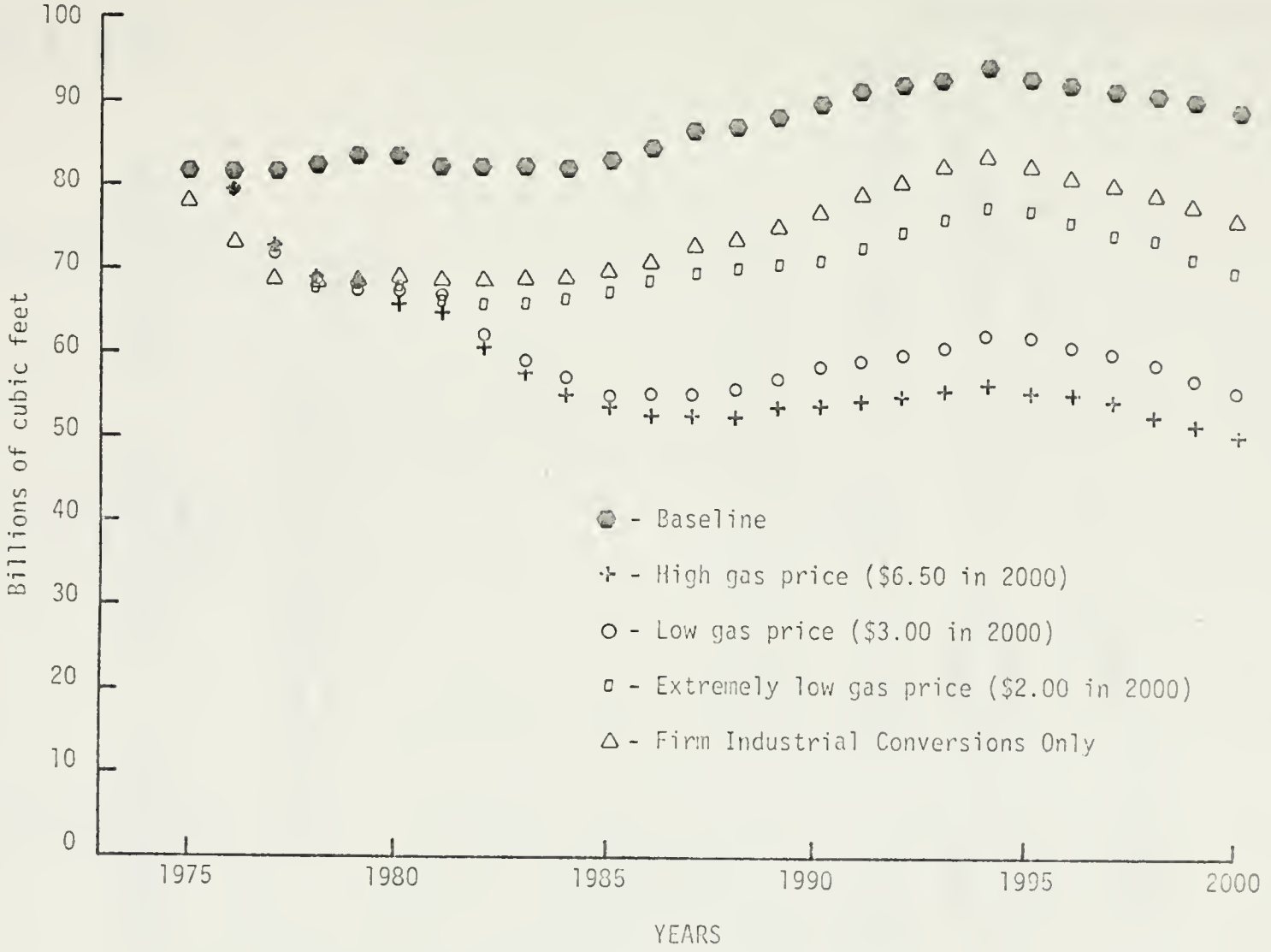

Figure 4.--Montana Natural Gas Demand

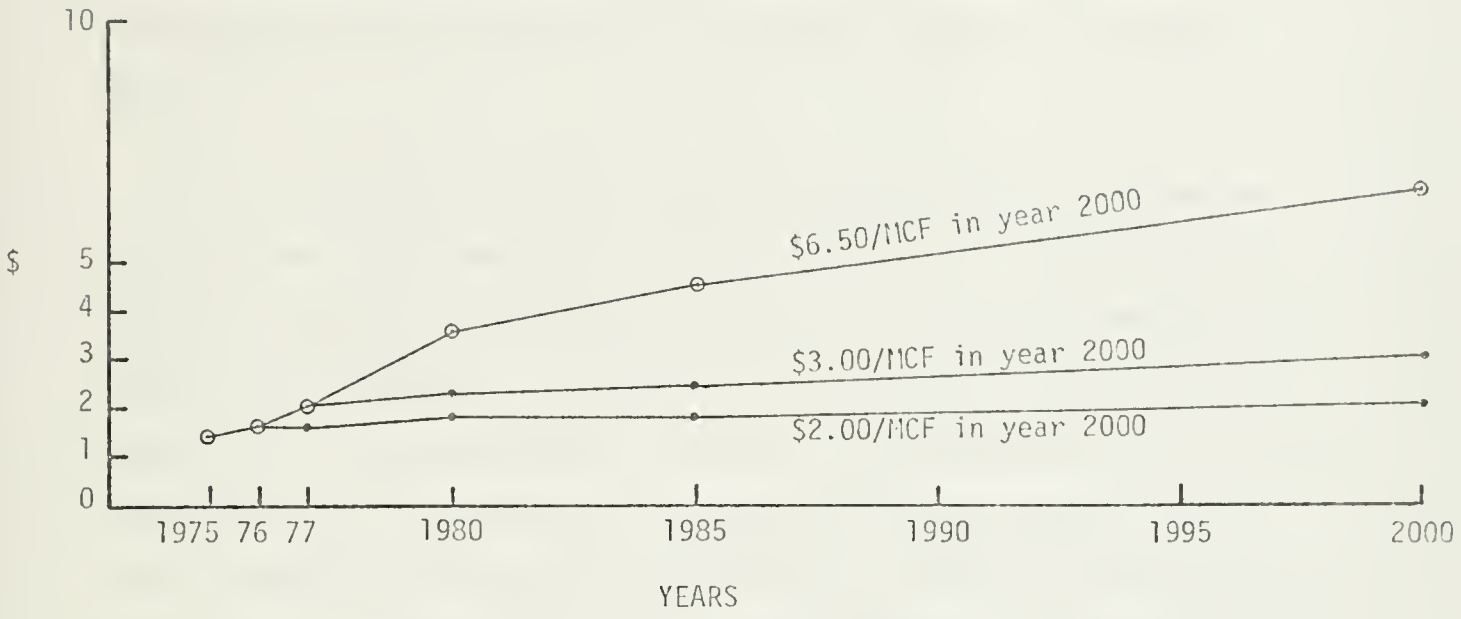

Figure 5.--Natural Gas Price Scenarios

Table 1.--Natural Gas Demand Level
(billions of standard cubic feet)

Year	PRICE Low ($2.00 in 2000)	Medium ($3.00 in 2000)	High ($6.50 in 2000)
1980	67	67	66
1985	67	56	54
2000	69	55	51

rate of 5.75% (price goes to $6.50/MCF in 2000) will drive gas demand down to about 60% of current levels by the year 2000.

It should be noted that the natural/synthetic gas demand projections shown here are probably maximum or "upper bound" estimates. Inter-fuel substitution for heating in the residential and commercial sectors was not modeled, nor was conservation in the commercial sectors. As the price of natural/synthetic gas increases in the future, these factors may become important and hence the demand for natural gas would be lower than that reported here. Unfortunately, the impact of these variables cannot be quantified at the present time.

Although we project a decreasing gas demand, our "most likely" projections still indicate a Montana natural/synthetic gas demand approaching 55-60 billion cubic feet per year in the year 2000.

IV. COMPETITIVE SUBSTITUTE AND SUPPLEMENTAL ENERGY FORMS

A number of substitute energy forms which are or could be competitive with natural/synthetic gas were identified in the course of this study. Only in a few industrial processes is gas actually needed. Natural/synthetic gas is primarily used as a source of heat or as a boiler fuel. Other energy forms can certainly be substituted for natural gas although they may not be as convenient or clean burning.

Both supplemental natural/synthetic gas supplies which could be utilized in the current natural gas delivery system and fuels requiring new energy delivery systems were identified and evaluated. Our inter-fuel substitution research focused primarily on the industrial sector in Montana since significant fuel substitution is currently ongoing in that sector and more is expected. Industries also require quantities of energy sufficient to make the utilization of new fuel delivery systems particularly attractive.

It was realized early that coal could be synthesized into substitute natural gas which could be delivered through existing pipelines and combusted in existing furnaces and burner heads without modification. Detailed technical and economic evaluations of the various processes for producing synthetic natural gas are being evaluated elsewhere.

Several additional supplemental sources of natural gas were also identified. As the price of natural gas increases,

Montana natural gas producers expect to be able to discover and produce more natural gas than in the recent historic past when natural gas prices were constrained to artificially low levels. Similarly, natural gas exploration is expected to increase in Montana's neighboring states. Montana could conceivably receive additional supplies of natural gas from these sources; however, neither the quantity nor the price of these additional supplies can be determined accurately at the present time.

A major reason for Montana's potential natural gas supply shortfall is a projected curtailment of natural gas supplies which are currently imported from Canada. Montana Power has the right to import 34.2 billion cubic feet (BCF) of natural gas from Canada during the year which will end May 13, 1977. They then expect to import 29.2 BCF annually until 1985. Under current circumstances Canadian gas will be completely eliminated by about 1989.[4] It is impossible to assess what the Canadian government may or may not do in the future. Large reserves of natural gas may exist in the Canadian Arctic which could be developed in the future. Based on current policies, however, it seems unreasonable to expect that additional supplementary gas supplies from Canada will become available to Montana.

Large reserves of natural gas are also known or believed to exist in the state of Alaska. These reserves are expected to be developed in the near future with the first gas supplies from this source possibly reaching the continental United States by 1982. Several routes have been suggested to bring

these supplies to the Continental United States and the matter is currently before the Federal Power Commission. Routes under consideration include pipelines through Canada along the Alcan Highway or down the MacKenzie Valley or a pipeline entirely through Alaska with Liquified Natural Gas (LNG) transport from Alaska to the Continental United States. Montana Power currently has an option to purchase 15 BCF of this gas annually.[5] However, the price of this gas may be $3/MCF or higher. The United States could also import LNG from foreign producers; but, this gas is also likely to cost over $3/MCF delivered and result in problems of supply security.

Several substitute energy forms which would require new or modified energy delivery systems were also identified. After preliminary review it was determined that low Btu coal gasification, direct coal combustion, and wood or wood waste combustion are possible economic substitutes for natural gas in the Montana industrial sector.

The wood products industry in Montana currently utilizes a large quantity of wood materials for energy generation. It is certainly possible that more could be used in the future. Montana currently produces over 8 million tons of wood logging residue per year which is either burned at the logging site or simply left piled in place.[6] Unfortunately, the long term delivered cost of this fuel is uncertain; and, the detailed assessment required to fully and accurately evaluate the potential for industrial utilization of this energy source was beyond the scope of this study.[7]

The direct combustion of coal as a substitute for natural gas is an alternative that several industries in Montana have recently turned to. In April 1976 the Ideal Cement Plant at Trident, Montana converted from natural gas to coal at a capital cost of $2.3 million, or approximately $1.20 per million Btu.[8] The Kaiser Cement plant near Helena, Montana, has a similar conversion to coal planned for the fall of 1977 at a capital cost of $1.5 million (∿$.90/million Btu).[9] Finally, the Great Western Sugar Company in Billings, Montana has announced plans to convert their sugar beet processing plant to coal. The capital cost of this conversion is reported to be $3.21 million (∿$2.70/million Btu).[10] Air pollution control costs for this facility are over $1.2 million. As can be seen above the capital costs of conversion to coal from natural gas are highly variable depending upon the particular industrial facility considered. Normalized conversion costs also vary inversely with the size of the facility converted. Fuel costs for coal delivered in Montana vary with location. Reasonable fuel cost (1975 dollars) estimates for Colstrip, Montana coal delivered to various Montana cities are: Butte $.70/million Btu; Missoula $.80/million Btu; Billings $.50/million Btu.[11] These coal fuel costs are certainly favorable when compared to natural/synthetic gas. Coal fuel costs do not seem likely to escalate rapidly in the future either.

Coal fired boilers are currently available utilizing either spreader grate or pulverized coal firing. Spreader grate boilers can be employed up to abut 0.5×10^6 lb of steam

per hour; however, the sized coal required for spreader grate operation may not be readily available.[12] Both boiler design and cost are particularly sensitive to the specific type of coal to be used. The Oak Ridge National Laboratory estimates that the annual cost of coal fired steam generation using western coal (8500 Btu/lb, 0.5%S) to be $1.53/million Btu. They also estimate that flue gas cleaning processes are available for ∿$.50/million Btu additional. The Oak Ridge estimate is split almost equally between capital and fuel costs.

The favorable economics of direct coal combustion is somewhat contrasted by its unfavorable environmental impact. Even with the "best available" air pollution control equipment, a coal fired boiler will emitt more pollutants than a conventional gas fired boiler. As previously noted a significant portion of the cost of coal fired boilers will be allocated to air pollution control. Although direct coal fired combustion (with proper pollution control) appears suitable for areas with adequate pollution dispersion potential, there are certain areas within the state (particularly in western Montana) where conventional coal combustion may simply be environmentally unacceptable.

Fluidized bed combustion, a new alternative process for direct coal conversion is currently under development and holds high promise for the future. Fluidized bed combustion is undertaken in an inert bed of coal ash and crushed limestone which rests on a bed of nozzles. Combustion air enters the bed through the nozzles, expanding the bed and causing it

to flow much like a liquid. Combustion is accomplished by introducing crushed coal and raising the bed to the ignition temperature of the coal. Volumetric heat release rates for fluidized bed combustion are on the order of 10 times those of conventional pulverized coal furnaces. Heat transfer surfaces are placed within the bed itself to absorb at least half of the heat released; the remainder of the heat released is collected by conversion surfaces. The combustion temperature of the bed is controlled to 1600-1800°F, considerably lower than conventional coal combustion. Since this combustion temperature is below the ash fusion temperature of coal, fluidized bed boilers can be designed independent of the type of coal to be used.

One of the major attractive features of fluidized bed combustion is its potential for air pollution emission control. Emission control is inherent in the fluidized bed combustion process. If limestone is injected into the fluidized bed, the bed turbulence will promote the reaction of sulfur dioxide with limestone and effectively remove sulfur from the system as dry calcium sulfate. Studies on the potential for limestone regeneration are currently underway.[13] The relatively low combustion temperature is the fluidized bed combustion temperature in the fluidized bed combustion process also limits the formation of oxides of nitrogen as does the minimum of excess air required for combustion.

There are no fluidized bed boilers commercially available in the United States today. A 30 Megawatt pilot fluidized bed

boiler was recently built in Rivesville, West Virginia and is currently beginning to undergo testing.[14] The Foster-Wheeler Company, manufacturer of some of the components of the Rivesville plant, indicate that they will warranty units of comparable size after 6 months of successful operation. The city of Linköping, Sweden is currently evaluating bids from several vendors to build a 15 MW boiler for its district heating system; hence, at-least intermediate sized fluidized bed boilers must be available in Europe.[15] Cost data for fluidized bed boilers are not yet fully developed in the United States. In 1970, Pope, Evans, and Rogers estimated that a fluidized bed boiler would cost approximately 1.4 times that of an equivalent gas fired boiler while a conventional spreader grate coal fired boiler would cost 2.35 times more than a gas fired boiler.[16] Oak Ridge National Laboratory predicts slightly lower steam costs ($1.65/million Btu versus $1.84/million Btu) for a fluidized bed boiler compared to a conventional boiler with stack gas desulfurization at an equivalent location. The lower costs for fluidized bed combustion are projected because of their more compact, standardized design, their reduced surface area, and the fact that they can be factory rather than field assembled. Applications of fluidized bed combustion for residential and commercial use are also being researched. The Montana Energy and MHD Research and Development Institute is particularly interested in a novel fluidized bed furnace that is applicable to home heating uses.

Fluidized bed coal combustion appears to be a particularly useful alternative to natural gas in Montana. While the process is not widely available now it seems to be ready for commercial development and must be considered when evaluating future alternatives. A detailed investigation of its suitability and potential as an alternative energy form appears warranted cn the basis of this investigation.

Finally, the potential applicability of low Btu coal gasification in the Montana industrial sector was evaluated. Low Btu coal gasification is essentially the first step in the process of producing synthetic pipeline quality natural gas. Coal is reacted with steam at high temperatures and pressures to produce carbon monoxide and hydrogen. If the reaction occurrs in the presence of air the resultant gas is diluted with nitorgen and has a heating value of approximately 125-150 Btu/cubic feet (SCF). If the initial reaction occurrs in an oxygen atmosphere the heating value of the resulting gas is increased to nearly 300 Btu/SCF. Conversion from natural gas to low Btu gas may require boiler derating and/or burner head modification depending on the exact heating value of the gas produced.

The technology of low Btu coal gasification is well developed. Before natural gas was widely available, low Btu gas (town gas) was used for home lighting and heating and in industrial processes throughout Europe and the eastern United States. There is a single brick manufacturer in Pennsylvania that currently gasifies about 85 tons of coal per day.[17] Worldwide there are many low Btu gasifiers operating. There are

several manufacturers that currently offer low Btu gasification reactors.

Low Btu coal gasification can be considerably cleaner than conventional direct coal combustion. Particulate air pollution control is to a large degree inherent in the gasification process since primarily gaseous products leave the reaction vessel. The gaseous stream is usually further scrubbed to remove most of the remaining entrained particulate matter. Sulfur also can be removed effectively since it will be in the gas stream as hydrogen sulfide. There are a number of commercial processes available to remove hydrogen sulfide; however, because sulfur removal is not inherent in the process, additional costs are incurred for this sulfur removal. Some manufacturers claim that by gasifying low-sulfur coal they can meet applicable federal air pollution regulations without sulfur removal. This tactic is probably inappropriate for Montana industry since many of the industries which could utilize low Btu gasification are in areas where ambient air quality standards are already approached or exceeded.

Several cost estimates for low Btu gasification have recently been developed. Low Btu gasification should inherently be cheaper than producing pipeline quality synthetic natual gas since neither the water gas shift reaction for relative hydrogen enrichment or methanation are required. Low Btu gasification facilities are also generally located at the load center so that gas transportation costs are minimized. Unfortunately, most recent reviews indicate that low Btu gas will

cost in the range of $3.00-$4.00/million Btus.[18,19] Costs increase as the size of the facility decreases. However, a number of sources still do predict that low Btu gasification will be less expensive than pipeline quality synthetic gas production.

In summary one can identify a number of supplemental or substitute energy forms which are applicable to Montana. These supplements or substitutes will all be much more expensive than natural gas historically has been. Some of these substitutes/supplements will undoubtedly be utilized in the future; however, their high costs signal that conservation will also have a significant impact on the future demand for natural/synthetic gas in Montana.

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